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An Economic Comparison of Aeration Devices for Aquaculture Ponds

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ABSTRACT

An economic engineering approach was used to estimate total aeration cost and to generate average cost curves of aeration. Fixed and variable costs were estimated for 23 different electric and tractor powered aeration devices. Least-cost aeration devices were selected for varying pond sizes. Below about 250 h of aeration per season, tractor-powered aeration devices were more efficient economically. Above approximately 250 h of aeration, electric aerators were more efficient. However, for ponds less than 2 ha in size, the propeller-aspirator-pumps (1–3 hp) were the least-cost system. For pond sizes above 0·4 ha, electric floating paddlewheels generally were the most cost efficient.

NOTATION

A	m × n matrix of technical coefficients
AC/kg DO	Average Total Cost per kilogram of dissolved oxygen transferred
ATC	Average total cost (TC/Q)
B	m × 1 vector of constraints
C	Objective function of linear programming model
E	1 × m vector of coefficients associated with each activity
Q	Quantity of output
TC	Total Cost (TFC + TVC)
TFC	Total Fixed Cost
TVC	Total Variable Cost
X	1 × n vector of activities

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INTRODUCTION

Catfish farmers are relying more and more on aeration devices to maintain adequate levels of oxygen in catfish ponds. Weight gain and feed conversion decline with low levels of dissolved oxygen, and prolonged exposure to low dissolved oxygen stresses fish and makes them more susceptible to bacterial infections. Different aeration systems present different levels of efficiency, economies of scale, operating costs and returns to capital investment. Although physical performance data are available for most commercial aeration systems, there are few economic analyses of optimum aeration systems.

Catfish farmers have traditionally utilized tractor-powered aeration devices in emergency situations when dissolved oxygen concentrations in fish ponds reach critical levels (Boyd, 1982; Boyd *et al.*, 1979; Tucker & Boyd, 1985). The two main types of tractor-powered aerators are pump sprayers and paddlewheels mounted on trailers.

Catfish farmers are investing in electric-powered (1–20 hp) aerators. Electric aerators can be run more frequently and for longer time periods than tractor-powered systems to prevent oxygen levels from reaching critically low levels (Hollerman & Boyd, 1980; Plemmons, 1980). Floating, electric-powered aerators include: paddlewheels, pump sprayers, vertical pumps, propeller-aspirator-pumps and diffuser aerators.

Nerrie (1988) reported survey results from West Alabama that supplemental aeration combined with higher stocking rates, increased catfish yield by 20%. Boyd *et al.* (1986) estimated that continuous nightly aeration would increase profits by 20–25%.

Performance data for both tractor-powered and floating, electric-powered commercial aeration devices have been developed (Boyd & Ahmad, 1987; Boyd & Martinson, 1984; Petrille and Boyd, 1984). Power consumption, motor output power, standard oxygen transfer rates and standard aeration efficiencies have been calculated. Various designs of paddlewheel aerators have been tested under different operating conditions (Ahmad and Boyd, 1988).

The purpose of this study was to estimate the total cost associated with different aeration systems and to generate average cost curves for different aeration devices. The study was limited to those aerators that have been performance tested at Auburn University (Boyd & Ahmad, 1987). Other aeration devices are available in different sizes, and new devices are being developed. This study is not a comprehensive analysis of aeration equipment, but rather provides guidelines, based on economic considerations, for the selection of aeration equipment.

THEORETICAL CONSIDERATIONS

Aeration or the addition of dissolved oxygen to a fish pond, represents an input into the production process similar to fertilizer or other inputs. The acquisition of an aeration device by a fish farmer represents a capital investment for which an annual charge (fixed cost) must be calculated and operating expenses (variable cost) incurred. Fixed costs, (depreciation for example) are often omitted from cost comparisons. Yet, capital goods, such as aeration devices, entail significant fixed costs. Annual depreciation charges are an accounting device to allocate revenue towards replacing a capital good when it no longer functions. If a catfish farm does not generate sufficient revenue to replace an aerator when it fails, then the farmer will not continue to aerate. In that case, aeration in the long run would not be feasible.

The cost of aeration can be quantified by determining fixed and variable cost associated with different aeration devices. The summation of fixed and variable costs is equal to total cost. Total cost, when divided by the quantity of output yields average total cost (ATC) as follows:

$$\mathrm{TFC} + \mathrm{TVC} = \mathrm{TC} \tag{1}$$

$$\frac{\mathrm{TC}}{\mathrm{Q}} = \mathrm{ATC} \tag{2}$$

where TFC = Total Fixed Cost, TVC = Total Variable Cost, TC = Total Cost, Q = Quantity of Output, and ATC = Average Total Cost.

Average total cost indicates the efficiency of production; it measures cost per unit of output. The most efficient level of production is that which produces the lowest cost per unit of output. This implies the greatest production per unit of input. While average cost measures efficiency of input use, it should not be the sole criterion for selecting an aerator. Farmers are concerned with profits which are calculated from output price as well as input cost. Average cost does not consider output price and does not measure profitability. What it does indicate is the most efficient level of usage of that particular input.

An economic engineering approach was used in this study to estimate total aeration cost and to generate average cost curves of aeration. This paper utilized kilograms of dissolved oxygen as the output from aeration. Fixed, variable and average total cost were calculated for various aeration devices. Depreciation, repair, operating and labor cost were separated out and compared on a percentage basis for different types of aerators. Additional break even production was calculated for a range of catfish prices at various specified desired levels of additions of pond oxygen. Finally, a computer simulation model was used to select the most cost efficient aerator for different pond sizes, and different amounts of aeration.

MATERIALS AND METHODS

Telephone interviews were conducted of 17 aerator manufacturers to determine capital investment requirements for commercially available aeration devices. Price lists, design specifications, composition of component parts and photographs were obtained of individual aeration devices.

Annual depreciation cost was estimated using the straight line method. The useful life of different aeration devices was estimated based on the materials used in the frame and the flotation devices. For example, floating steel drums will last longer than styrofoam flotation units.

Repair and maintenance cost was estimated for individual aeration devices based on information obtained from telephone interviews with 3 manufacturers of electric motors used in constructing aerators and with 4 manufacturers of the gear boxes and bearings used in aerator construction. Although electric aerators have not been in use long enough to collect farm-level repair data, the general frequency of repair of this type of electric motor, gear assembly, etc under the type of conditions often found on fish farms were estimated by these manufacturers.

For example, the larger the horsepower of an electric motor, the more costly it is to repair. The more moving parts any machine has, the greater the likelihood of mechanical failure. Motors mounted below the water surface are more difficult to repair and will entail a greater cost.

Hourly operating cost as developed by Boyd & Ahmad (1987) were utilized. These costs were based on an electricity cost of $0·075 per kilowatt-h.

Average total cost was calculated per kilogram of dissolved oxygen (AC/kg DO) produced. Average total cost per kilogram of dissolved oxygen per horsepower might be a more appropriate basis for comparing electric aerators, but tractor-powered aerators could not be compared with this indicator.

AC/kg DO was calculated for 10 levels of aeration usage that ranged from 50–1850 h of aeration per year. According to Boyd *et al.* (1979) emergency aeration was used at least 6 nights per season in commercial catfish ponds. At 8 h per night, this would represent a minimum of 48 h of aeration per season. If aeration was used nightly for 10 h per night over a 6 month period, the total number of h of aeration would be 1800. The range utilized in the analysis included lower limits where only emergency aeration has been used in the past to continuous nightly aeration over the entire growing season.

A linear programming computer model was developed to select optimal aeration systems based on minimization of total annual cost. The generalized form of the linear program was to

Minimize	$C = EX$
Subject to	$AX \geqslant B$
And	$X \geqslant 0$

Where C = objective function, $E = 1 \times m$ vector of coefficients associated with each activity, $X = 1 \times n$ vector of activities, $A = m \times n$ matrix of technical coefficients, and $B = m \times 1$ vector of constraints.

RESULTS AND DISCUSSION

Capital investment and depreciation

Capital investment and depreciation cost per unit varied widely for different aeration systems. Capital investment ranged from \$450 to \$3500 (Table 1). Annual depreciation cost fluctuated from \$183 to \$1426 (\$33 to \$1603 per horsepower).

Floating electric paddlewheels had the highest mean capital cost followed in descending order by floating pump sprayers, diffusers, floating vertical pumps and propeller-aspirator-pumps. On a per horsepower basis, however, the diffuser aerators were twice as expensive as the next highest, floating vertical pumps. A similar pattern was observed for annual depreciation cost. Per horsepower, the least expensive was the floating pump sprayer followed by floating electric paddlewheels, propeller-aspirator-pump, diffusers and vertical pumps.

The variation in depreciation cost is a significant consideration. Farmers should carefully evaluate the materials used in the construction of a particular aerator. Sturdily built aerators with fewer movable parts may last two or three times as long as other aerators. This would result, over time, in the purchase of fewer replacement aerators and a significantly lower long-run cost to the firm.

Repair and maintenance cost

Estimated repair cost of electric motors varied with the horsepower of the motor. Larger horsepower motors entailed greater repair cost than

TABLE 1
Capital Investment and Annual Depreciation Cost for Aeration Devices[a] Used in Catfish Ponds

Aerator	*hp*	*Capital investment ($)*	*Useful life[b] (year)*	*Annual depreciation ($)*
A. *Electric*				
1. Floating paddlewheels				
n	6	6	6	6
range	2–10	1 045–3 000	2–6	261–1 325
$\bar{x}$	9	2 558	4	661
2. Floating vertical pump				
n	5	5	5	5
range	0·33–10	450–2 852	1–3	225–1 426
$\bar{x}$	3	1 619	2	801
3. Floating pump sprayer				
n	3	3	3	3
range	10–20	2 450–2 625	3–5	490–833
$\bar{x}$	17	2 525	4	660
4. Diffuser				
n	2	2	2	2
range	0·75–1·7	925–3 500	3–5	411–412
$\bar{x}$	1	2 212	4	412
5. Propeller-aspirator-pump				
n	3	3	3	3
range	0·5–3·0	550–750	3–3	183–250
$\bar{x}$	1·5	650	3	217
B. *Tractor-Powered*				
1. Paddlewheel				
n	1	1	1	1
range	na	na	na	na
$\bar{x}$	na	2 650	10	265
2. Pump Sprayer				
n	3	3	3	3
range	na	2 350–3 000	10–10	235–300
$\bar{x}$	na	2 683	10	268

[a]See Boyd & Ahmad (1987) for detailed description of aerators.
[b]Useful life is estimated based on materials used in construction of the frame and flotation devices.
na = not applicable.

smaller horsepower motors. More complex systems with more moving parts have a greater likelihood of mechanical failure and have a greater repair cost.

Repair cost ranged from \$44 to \$450 per aerator per year (Table 2). The floating pump sprayers, that had the largest electric motors, had the highest repair cost, followed by paddlewheels, diffusers, vertical pumps and propeller-aspirator-pumps.

The floating electric paddlewheels all have either gear motors, gear boxes or gear reducers. There is a greater risk of mechanical failure due to these gears that results in greater repair cost.

Table 2 shows that total repair and maintenance costs were highest for paddlewheel aerators, followed by pump sprayers, diffusers, vertical pumps, and propeller-aspirator-pumps. On a per-horsepower basis,

TABLE 2

Estimated Repair and Maintenance Cost for Aeration Devices[a] Used in Catfish Ponds

Aerator	*Electric motor repair cost (\$)*	*Gear maintenance cost (\$)*	*Total*	
			(\$)	*(\$hp^{-1})*
Electric				
1. Floating paddlewheels				
n	6	6	6	6
range	55–120	104–300	159–420	38–80
$\bar{x}$	107	256	363	47
2. Floating vertical pump				
n	5	na	5	5
range	44–120	na	44–120	12–133
$\bar{x}$	69	na	69	54
3. Floating pump sprayer				
n	3	na	3	3
range	108–450	na	108–450	11–22
$\bar{x}$	336	na	336	18
4. Diffuser				
n	2	na	2	2
range	48–110	na	48–110	64–65
$\bar{x}$	79	na	79	64
5. Propeller-aspirator-pump				
n	3	na	3	3
range	45–55	na	45–50	18–90
$\bar{x}$	50	na	50	53

[a]See Boyd & Ahmad (1987) for detailed description of aerators.
na = not applicable.

pump sprayers were the least-cost, followed by paddlewheel, propeller-aspirator-pumps, vertical pumps and diffusers.

Operating cost

Table 3 presents operating cost (calculated at $0.075 per kWh) for the aerators studied. Cost per hour ranged from $0.025 to $1.42 per h for electric aerators. Per horsepower-h, all aerators had similar cost; larger horsepower motors had greater cost per h.

The operating cost of tractor-powered aerators was substantially greater than that of the electric aerators. This cost represents tractor cost that includes fuel, oil and depreciation of the tractor. Tractor cost, however, varied with use of the tractor. Fixed cost varies as well as fuel and oil cost. The $12.00 cost in Table 3 is a representative cost based on an average amount of aeration.

The major cost of tractor-powered aerators is operating cost, while the cost of operating an electric aerator is a much lower percentage of total cost. Operating costs for tractor-powered aerators were 75% of total cost at 250 h of aeration and 86% of total cost at 1250 h of aeration, Table 4. Electric aerators, however, had operating costs that were 4–20% of total cost at 250 h of aeration and 11–49% of total cost at 1250 h of aeration.

Depreciation cost, expressed as a percentage of total cost, was higher for electric aerators. At 250 h of operation, depreciation cost comprised 50–80% of total cost. This percentage declined to 25–52% of total cost at 1250 h of aeration. Tractor-powered aerators, on the other hand, had depreciation cost of only 11% of total cost at 250 h and 1% of total cost at 1250 h of aeration. Depreciation on the tractor is not included in this calculation. The difference in depreciation cost reflects the greater capital investment and shorter useful life of electric aerators.

For electric aerators the fixed cost of depreciation is a significant cost. In choosing an electric aerator, the catfish farmer should consider carefully the materials used in construction and the quality of construction to ensure a longer life. For tractor-powered aerators, operating costs are more significant and aerator selection should primarily consider operating efficiency.

Average cost

Average Total Cost per kilogram of O_2 (AC/kg DO) produced declined with greater output for all electric aerators (Fig. 1). Average cost declined most rapidly when aeration was increased from 50 h to 250 h.

TABLE 3
Operating Cost for Aeration Devices Used in Catfish Ponds

Aerator	*SOTR* *(lbs O_2 h^{-1})*	*Cost*		*Aeration cost/lb O_2*
		(\$ h^{-1})	*(\$ $(hp\text{-}h)^{-1}$)*	*(\$ $(lb\ O_2)^{-1}$)*
A. *Electric*				
1. Floating paddlewheels				
n	6	2	6	6
range	5·4–45·9	0·16–0·73	0·06–0·08	0·0155–0·03
$\bar{x}$	36	0·57	0·0678	0·0183
2. Floating vertical pump				
n	5	5	5	5
range	0·7–24·0	0·025–0·80	0·067–0·080	0·026–0·036
$\bar{x}$	8	0·245	0·0726	0·0314
3. Floating pump sprayer				
n	3	3	3	3
range	26·4–29·8	0·57–1·42	0·057–0·071	0·018–0·048
$\bar{x}$	27·5	1·04	0·062	0·036
4. Diffuser				
n	2	2	2	2
range	1·4–2·4	0·05–0·12	0·067–0·071	0·036–0·050
$\bar{x}$	1·9	0·085	0·069	0·043
5. Propeller-aspirator-pump				
n	3	3	3	3
range	1·4–9·3	0·035–0·210	0·07–0·07	0·023–0·032
$\bar{x}$	4·3	0·105	0·07	0·0267
B. *Tractor-Powered*				
1. Paddlewheel				
n	1	1	na	1
range	na	na	na	na
$\bar{x}$	65·7	12	na	0·183
2. Pump sprayer				
n	3	3	na	3
range	17·3–46·9	12–12	na	0·256–0·694
$\bar{x}$	28	12	na	0·517

Source: Boyd & Ahmad, 1987; Ogburn & Roberts, 1987.
na = not applicable.

(A quantity of 50 h of aeration represents 10 nights of aerating 5 h each.) Tractor and other capital equipment cost often exhibit similar average total cost curves.

Electric paddlewheel and pump sprayer average cost were of similar magnitude. Vertical pump and propeller-aspirator-pump cost were slightly higher with diffuser aerators being substantially higher.

Figure 1 illustrates the average total cost curves of the most efficient aerator of each type. Great differences in horsepower within each aerator type result in widely varying cost. However, the aerators vary widely in efficiency also. The most efficient vertical pump had a similar

TABLE 4
Cost Decomposition Expressed as a Percent of Total Cost for 250 and 1250 Hours of Aeration Per Year

Type of aerator	*Depreciation*		*Gear & motor repair*		*Operating*		*Labor*	
	250 h (%)	*1250 h (%)*	*250 h (%)*	*1250 h (%)*	*250 h (%)*	*1250 h (%)*	*250 h (%)*	*1250 h (%)*
A. *Electric*								
1. Paddlewheel	51	32	28	17	11	35	5	16
2. Vertical pump	80	52	7	4	6	20	7	24
3. Pump sprayer	50	25	25	13	20	49	6	14
4. Diffuser	72	42	14	8	4	11	13	39
5. Propeller-aspirator-pump	59	28	14	6	7	17	20	48
B. *Tractor-Powered*								
1. Paddlewheel	11	1	na	na	75	86	14	13
2. Pump sprayer	11	1	na	na	75	86	14	13

na = not applicable.

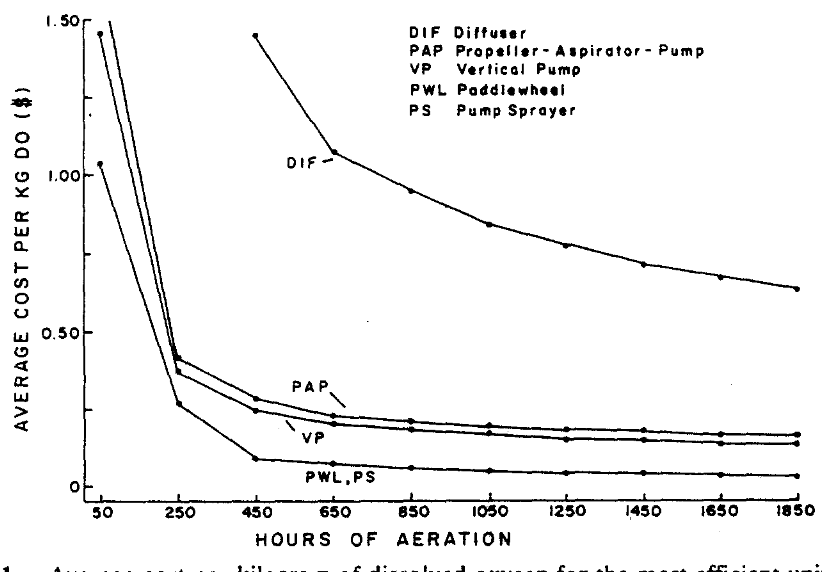

Fig. 1. Average cost per kilogram of dissolved oxygen for the most efficient unit of 4 types of aeration devices.

ATC curve to that of the paddlewheel and pump sprayer. The other vertical pumps, however, had ATC ranging from 5 to 20 times higher than that of the most efficient. The electric paddlewheels, on the other hand, were remarkably similar in Average Total Cost.

Tractor-powered aerators had Average Total Cost curves that declined from 50 to 250 h of aeration, but at aeration levels greater than 250 h per season, continued to increase with increasing amounts of aeration (Fig. 2). Increasing ATC indicates the rapidly increasing tractor cost associated with long-term use of tractor-powered aerators.

At low rates of aeration (50 h), both tractor-powered aeration devices had lower ATC than the most efficient electric aerator (PWL). At 250 h of aeration, ATC was similar although somewhat higher for tractor-powered aerators. At greater aeration levels, tractor-powered aeration cost became more and more expensive relative to electric aerators.

Figures 1 and 2 show that a farmer utilizing less than 250 h of aeration per season should continue to rely on tractor-powered aeration devices. A farmer that plans to aerate more often and for longer periods should plan to invest in electric aerators.

Aerator selection and pond size

The amount of oxygen that must be added to a pond during the night will vary depending upon phytoplankton populations, feeding rates and BOD, among other things. Two levels of oxygen to be added to the pond were selected for the following analysis.

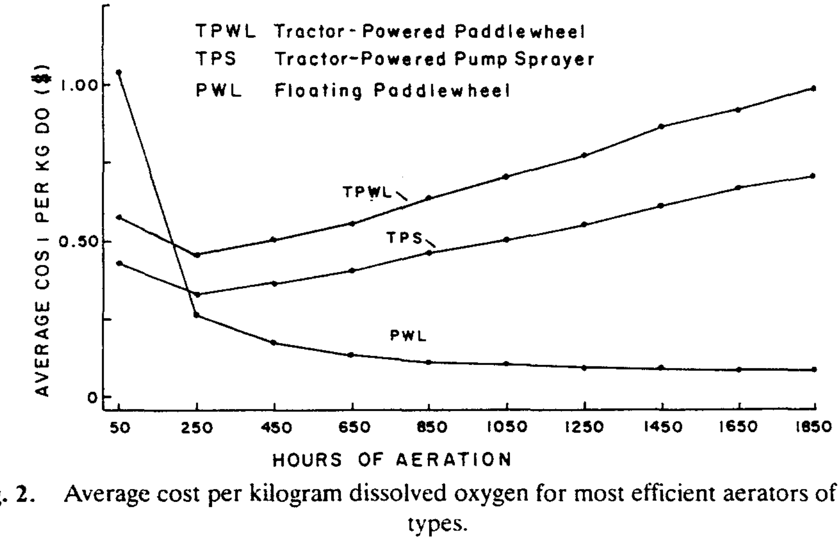

Fig. 2. Average cost per kilogram dissolved oxygen for most efficient aerators of three types.

Least-cost aeration systems were selected based on additions of 4 and 7 ppm of dissolved oxygen for the following pond sizes: 0·04 ha, 0·20 ha, 0·40 ha, 2·00 ha, 4·00 ha and 8·00 ha. Table 5 presents the least-cost aerators for these pond sizes to add 4 ppm and 7 ppm, respectively, of DO to one pond during 1 night.

For pond sizes ranging from 0·04 ha to 0·40 ha, the propeller-aspirator-pump aerators were selected most often. for both levels of DO added nightly to the pond. The 2·00 ha pond with 4 ppm DO added selected a PS aerator. This same size pond, however. to add 7 ppm to the pond, selected a paddlewheel aerator. The larger pond sizes were more effectively aerated with paddlewheel aerators.

The propeller-aspirator-pump aerators were selected most often for smaller ponds because the capital investment and annual depreciation charges per kg of oxygen transferred were significantly lower than for other types of low-hp aeration devices. For example, one propeller-aspirator-pump model had a much lower purchase price than a smaller-hp paddlewheel aerator. Operating cost per kg of oxygen transferred was also slightly lower for the propeller-aspirator-pump models than for other low-hp aerators.

Several new models of low-hp paddlewheel aerators have been developed recently, New, sturdier models exhibiting efficiencies comparable to the larger-hp models at lower purchase prices may compete with the propeller-aspirator-pump models for small ponds.

The paddlewheel aerator that entered most consistently as the least-cost option for larger ponds had the lowest annual depreciation, a low

TABLE 5
Least-Cost Electric Aeration Systems for Varying Pond Sizes at Two Levels of Oxygen Added

Pond size (ha)	*Oxygen added*	
	4 ppm (aerator)	*7 ppm (aerator)*
0·04	propeller-aspirator-pump (0·5 hp)	propeller-aspirator-pump (0·5 hp)
0·20	propeller-aspirator-pump (1·0 hp)	propeller-aspirator-pump (3·0 hp)
0·40	propeller-aspirator-pump (3·0 hp)	propeller-aspirator-pump (3·0 hp)
2·00	pump sprayer	paddlewheel
4·00	paddlewheel	paddlewheel
8·00	paddlewheel	paddlewheel

repair cost and the lowest operating cost of similar-size aerators. However, it also had the lowest oxygen transfer rate and highest cost per pound of oxygen transferred of that size and type of aerator. For larger ponds (8 ha and above) adding 7 ppm DO nightly, the model selected the paddlewheel aerator with the best oxygen transfer rate. At greater levels of use, the depreciation cost is less significant and operating cost efficiency becomes more important.

Aerating 30, 60 and 90 nights per season were tested, but did not alter the choice of aerator. The choice of aeration system was determined by the number of aerators required per night to add sufficient oxygen.

Horsepower selected ranged from 5–15 hp per ha to add 7 ppm DO. To add 4 ppm DO, horsepower ranged from 2·5 to 12·5 hp/ha.

For a given price of catfish ($0·60/lb), Table 6 presents the minimum additional production of channel catfish that would be required to cover the cost of aeration of different aerators. Data for the most efficient aerator of each type were utilized. For the low-cost aerators, at high levels of aeration, the additional production required would be approximately 400 kg/ha/yr. For an average yield of 3000 kg/ha/yr, this would represent a 13% increase in yield. Research suggests that continuous nightly aeration may increase production of catfish by 20% (Nerrie, 1988). Continuous nightly aeration would produce sufficient additional poundage of fish to more than compensate for the additional cost. Hence, continuous nightly aeration would increase farm income.

TABLE 6
Minimum Additional Production of Channel Catfish Required to Cover Additional Cost of Aeration, Most Efficient Aerator of Each Type (P = $0·60)

Hours of aeration (hours)	*Paddlewheel (kg ha^{-1} yr^{-1})*	*Vertical pump (kg ha^{-1} yr^{-1})*	*Pump sprayer (kg ha^{-1} yr^{-1})*	*Diffuser (kg ha^{-1} yr^{-1})*	*Propeller-aspirator-pump (kg ha^{-1} yr^{-1})*
50	172	150	113	604	208
250	206	191	145	699	272
450	241	233	178	791	337
650	275	275	210	885	401
850	309	316	243	978	466
1 050	343	358	276	1 072	530
1 250	377	400	308	1 166	594
1 450	411	441	341	1 259	658
1 650	445	483	373	1 353	723
1 850	479	525	406	1 447	788

Limitations of the data

This study was based on cost data collected for aerators that have been performance tested at Auburn University. The paddlewheel aerators that were consistently selected for larger pond sizes generally were constructed with a 10-hp motor. These larger units are too powerful for small ponds. Yet, there are few manufacturers of smaller horsepower paddlewheels and these have not been performance tested.

The propeller-aspirator-pump aerators that have been tested for performance are small, 1–3 horsepower units, and were cost efficient. Comparisons between large horsepower propeller-aspirator-pumps and paddlewheels could not be made. Neither could small-hp paddlewheels be compared to propeller-aspirator-pumps.

The lack of data of the full spectrum of aeration devices precludes definitive conclusions about choice of aerators. The data available can serve to provide general guidelines about the economic trade-offs of these devices.

CONCLUSIONS

An economic engineering approach was used to estimate total aeration cost and to generate average cost curves of aeration. Fixed and variable costs were estimated for 23 different electric and tractor-powered aeration devices. Average cost curves were developed for the main types of aeration devices for varying amounts of aeration. Least-cost aeration devices were selected for varying pond sizes.

Below about 250 h of aeration per season, tractor-powered aeration devices were more efficient economically. Above about 250 h of aeration, electric aerators were most efficient. However, for small ponds, the propeller-aspirator-pumps (1–3 hp) were the least-cost system. For pond sizes above 0·4 ha, the electric floating paddlewheels generally were the most cost effective.

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